CHAPTER 7

SOLID-STATE ELECTRONIC EQUIPMENT

7-1. Solid-state maintenance.

Electronic system maintenance is required for proper operation. Specific maintenance procedures should be obtained from the equipment manufacturer. Preventing the solid-state component from failing will increase the electronic system's availability. Preventive maintenance applied to electronic systems should be directed toward minimizing the chance of component failures thereby reducing the causes of system failure. There are two primary causes of solid-state component failure. First is heat caused by overloading, surface contamination or poor ventilation. The second is vibration caused by mechanical stress, shock, moisture due to environment, overvoltage, electrical spikes or static discharge while handling components.

a. Preventive measures. The following are general preventive measures applicable to individual equip ment within a system. Detailed preventive maintenance of specific solid-state components is covered later in this chapter.

(1) *Keep equipment clean.* Limit overheating and the chances of current leakages or flashover by periodic vacuuming or blowing out dirt, dust, and other surface contaminants from the equipment enclosures. Use a non-conducting nozzle on the vacuum or air hose (a metal nozzle can cause component damage and/or breakdown). Do not use high pressure air, it may damage components.

(2) *Keep equipment dry.* Space heaters will prevent the accumulation of moisture and subsequent corrosion thereby limiting intermittent component failures.

(3) *Keep equipment tight.* Tight connections and secure leads and contacts limit adverse effects of vibration.

(4) *Keep equipment cool.* Proper ventilation limits overheating due to high ambient temperature.

b. System checks. The following are basic system checks which may be applicable to components and subassemblies within a given system.

(1) *Magnetic device.* Check the operation of magnetic and contact-making devices in accordance with applicable instructions. Brushes in motors (used for all motor driven position adjusters, etc.) and all exposed brushes or contact buttons for rheostats, potentiometers, and variable transformers should be inspected every 12-18 months. For frequent operations or adverse operating conditions, such as very dusty, humid, and corrosive areas, inspections may have to be done every 4-6 months. If arcing occurs, or if the brushes are badly worn, replacement is recommended.

(2) *Input and output.* Input and output signal voltages, which can be considered important indicators of operating conditions, should be checked on the regulator or function panels. A high input impedance voltmeter should be used for these measurements. The checks should be performed every 12-18 months. Data should be recorded for future reference and the test points where the data was taken should be fully explained.

(3) *Semiconductor-controlled rectifier (SCR).* Spot check operation of SCR's by observing their neon lamp monitors. All lamps should either glow or not glow as a group. When lighted, all lamps should glow with about the same intensity with one electrode in each lamp glowing somewhat more brightly than the other.

(4) *Planned outages.* For planned outages, the following maintenance should be performed:

(a) General cleaning with either low pressure, dry air and/or a vacuum cleaner. Any air intake filters should be inspected, cleaned if possible, or replaced at this time.

(b) Check all brushes, small auxilliary motors, variable slide-wire resistors (rheostats), potentiometers, and variable transformers.

(c) Inspect all control and power relays for freedom of operation and the condition of their contacts. Also, check for failed surge suppression devices when these are provided across the operating coil connections.

(d) Check for any loose connections or evidence of heating on large cable, bus, and large SCR's or rectifiers. Correct cause when found.

(e) Check SCR or rectifier legs and corresponding fuses with an ohmmeter. Test all elements of parallel groups individually.

7-2. Solid-state components.

Maintenance procedures for solid-state component are designed to detect evidence of abnormal heating, moisture, dust and other contaminants; promote good reliability and minimize downtime; prolong the useful life of the equipment; and, recognize repeated component failures and take corrective actions.

a. Static testing. For this work, static testing is taken to mean one or more electrical tests, performed on a given component, using very low voltages or powers. Furthermore, these tests are designed to give a very general idea as to the component's overall condition and not its performance per published specifications. To test most capacitors, rectifiers (diodes), resistors, potentiometers, SCR's, and bipolar junction transistors, the volt-ohmmeter (VOM) is the recommended instrument (para 13-2). There are many types and models available; however, the analog meter still serves very well for static testing. It should be noted that meters with very low energy resistance test ranges will not produce the same results described in the paragraphs below. Most all new digital models have the low energy resistance test feature. The manufacturers have recognized this problem and usually provide one additional function marked "diode test" or simply the ANSI symbol for a diode. This type of test is also different from those described below. The diode test feature differs from the resistance test, using an ohmmeter, in that the instrument generates a freed current (about 10-100 milliamperes) and passes it though the device under test. The corresponding voltage generated across the device terminals is usually the reading that appears on the instrument's display. The maximum voltage is never more than the battery voltage used to power the meter. The ohmmeter applies a relatively constant voltage and allows the current to vary in proportion to the total circuit resistance (Ohm's Law). Before testing, the ohmmeter must be calibrated for zero ohms. This nulls out the test lead resistance; the test probes are touched together and the meter reading is adjusted to indicate zero. Then, the particular component to be tested must be isolated from the rest of the circuit. This is done by disconnecting at least one lead of the component.

b. Capacitors. A capacitor stores electrical energy for dissipation as needed in an electrical circuit. The amount of charge stored depends upon the value of the capacitor (expressed in pico-, nano-, or microfarads) and the applied voltage. There are many types of capacitors used in power electronic and control equipment (fig 7–l). The more commonly used types are: oil-impregnated and non-polarized; polarized aluminum electrolytic; polarized wet slug and dipped tantalum; non-polarized wet slug and dipped tantalum; and, non-polarized paper, plastic film, mica, or ceramic capacitors. A capacitor is defective, or will soon be defective if it has a damaged case, is leaking fluid or electrolyte paste, or testing shows it to be nearly shorted or completely open.

(1) *Inspection for oil leaks.* Leaking capacitors can be found by locating the oil or fluid that has seeped from a cracked case or relief plug. A leaking capacitor may be kept in service for brief emergency periods but should be replaced before it fails altogether, or the leaking fluid damages other equipment. Before rejecting a capacitor for leaking oil, be sure the oil was not deposited by some other apparatus or another capacitor located above. An effort should be made to determine the nature of the leaking fluid. If the capacitor is not specifically stamped: "NON-PCB" or "NO PCB's", then the Hazardous Waste Coordinator should be contacted and the capacitor disposed of as recommended by that Office.

(2) *Testing.* Open or solid capacitors maybe found by using an ohmmeter to test as follows:

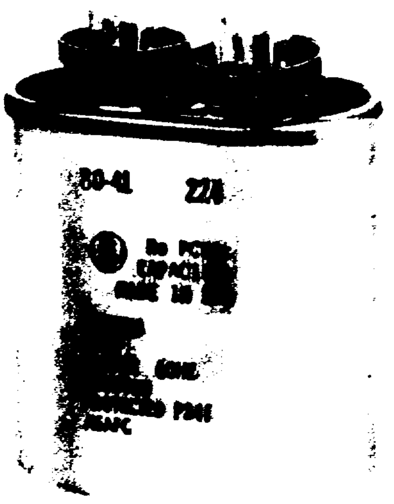
(a) Identify the polarity of the terminals when electrolytic capacitors are to be tested. Always test with the plus (+) lead of the meter connected to the terminal marked plus (+) or the red dot. Reversed polarity, even at low voltages, causes high dissipation in the electrolyte paste and gives poor test readings on a possible good unit.

(b) For values under one (1) microfarad, use the "X1OO" scale. For higher values, use either the "X100" or the "10X" scale.

(c) Discharge the capacitor before testing. Use a 100-1000 ohm resistor to limit the discharge current. Remove the resistor connection.

(d) Connect the test probes and note the meter deflection. If the capacitor is open, the ohmmeter will continually indicate infinity ohms. The meter needle will not move the moment the leads are touched to the capacitor terminals. Replace capacitors that are open circuit. If the capacitor is shorted, the meter needle will immediately deflect to zero or some low value and remain there. Replace capacitors that are shorted. A good capacitor will cause the meter needle to deflect toward zero ohms the moment the leads are touched to its terminals. However, the needle will begin to indicate ever-increasing resistance as the capacitor charges up. The amount of initial deflection and the rate of return of the needle depend on the value of the capacitor and the ohms scale multiplier selected. Capacitors that are "leaking electrically" will cause the meter needle to deflect as usual; however, the final resistance value may be only several hundreds of ohms rather than the several thousands that can be expected. Capacitors not properly isolated from the circuit during the test often give this kind of reading because of the other components connected in parallel. If it is certain the capacitor alone is reading this way, it should either be replaced or retested with an analyzer. All of the test results described above will be more readily understood if several values of capacitors that are known to be good are tested first.

c. Rectifiers and semiconductor-controlled rectifiers (SCR). A rectifier (diode) is a solid-state device that limits the flow of electrical current to one direction. The semiconducting material within the device acts as an insulator in one direction (within certain



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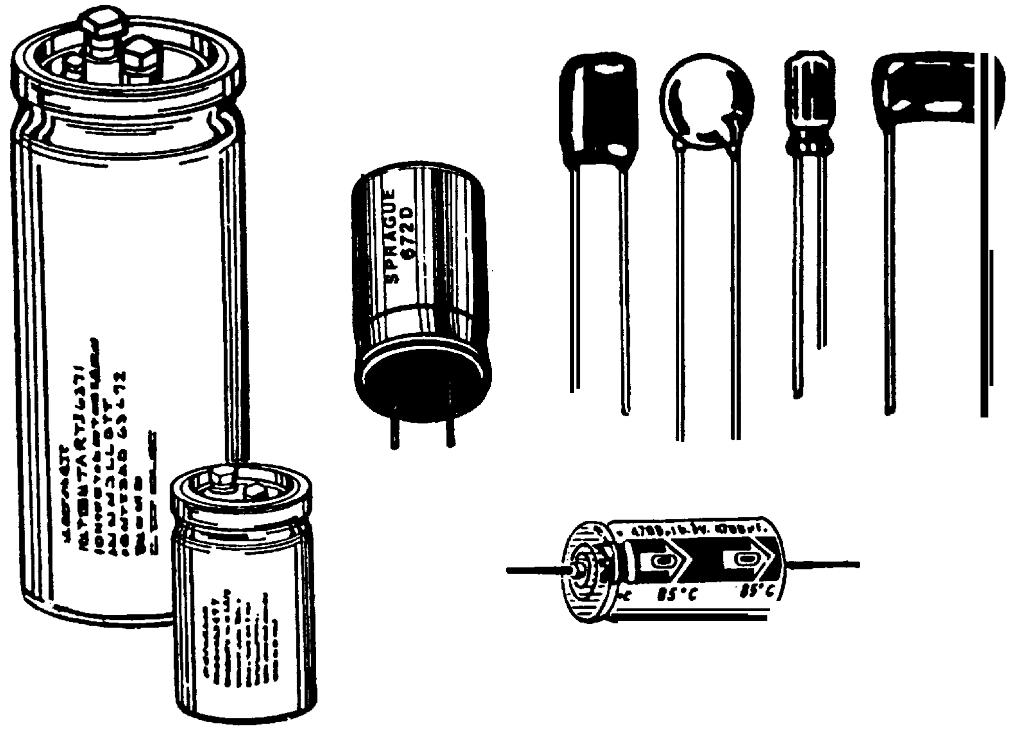


b.

Figure 7-1. Typical Capacitor Types: a) Oil-filled AC, snubber capacity b) Electrolytic, ceramics and plastic film types for DC applications voltage limits) and as a fairly good conductor to current flow in the opposite direction. The ohmmeter may be used to measure the forward resistance (conduction) and the reverse resistance (insulating or blocking) of the device in order to determine its overall condition. Testing should be done as shown in figure 7–2c. Connect the ohmmeter to read resistance in the forward direction. The reading should range between 6-35 ohms. This is the range for general purpose rectifiers. Very small, signal type rectifiers may read as high as 70-100 ohms. Very large current capacity rectifiers may read between five and ten ohms. Finally, germanium diodes read lower than those made from silicon, and fast recovery types read lowest of all: two to six ohms. Connect the ohmmeter to read resistance in the reverse direction. The reading obtained should be between 10,000 and 100,000 ohms or possibly more. The reading tends to be near the lower end of the range for large current capacity types. If the diode is good, the values listed above will be obtained. Readings of one (1) ohm or less mean the device is damaged or shorted. Reverse direction readings less than 10,000 ohms generally mean the device is damaged or electrically leaking. In both cases, the unit should be replaced.

(1) *Semiconductor-controlled rectifier (SCR). The* SCR is a diode with the ability to be forced into conduction by the application of a gate signal. The SCR cannot conduct in the reverse direction if it is a good unit. However, the SCR will not conduct in the forward direction either until a small gate voltage is applied. Once in conduction, the SCR remains that way until its current (not the voltage) drops below the minimum holding value for that particular device. The SCR should be tested like the diode rectifier (fig 7–2d) but with the following modifications to the procedure:

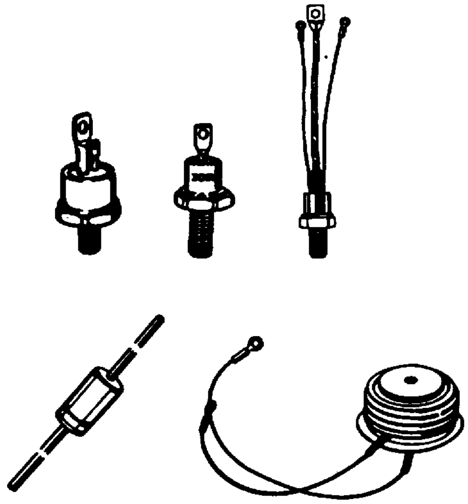
(a) Connect the ohmmeter to read forward resistance. The meter needle should read infinity ohms before a gate-cathode voltage is applied. Connect an additional voltmeter between the gate and cathode leads of the SCR. Apply an adjustable DC voltage to these leads and measure the voltage needed to start conduction. The ohmmeter will give readings like those for the diode when conduction has been established. Note the gate-cathode voltage when conduction starts. It should be between 0.6 and 1.3 volts for the most general purpose units.

(b) Disconnect the gate lead. The SCR will remain in conduction until the ohmmeter leads are removed. This condition depends on two things: first, the particular SCR must have a very low holding current; second, the battery in the ohmmeter must be fresh or fully recharged. A gate to cathode resistance check may be applied also. With plus (+) on the gate, the ohmmeter reading will be similar to the diode forward reading. There is no blocking reading for the reverse. Readings for the cathode to gate connection are generally only 10-50% higher than those obtained in the forward mode. If a test battery (fig 7–2d) is not available for the conduction test, an alternate test can be done using only the ohmmeter. This simplified test is harder to interpret and is less accurate than the procedure described above. To do the test, setup as in paragraph *(a)* above. In place of the test battery, touch the gate lead to the anode (+) lead. The SCR should begin to conduct.

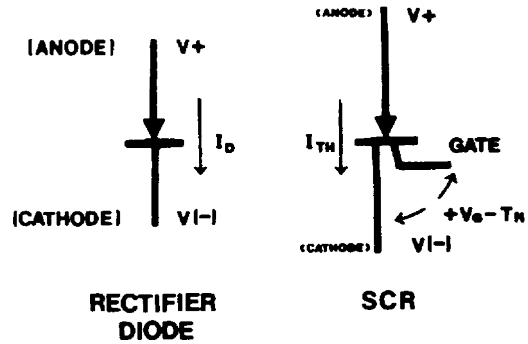
(2) *Other devices.* There are many styles and types of devices for both diodes and SCR's. It is beyond the scope of this manual to describe all of them in detail. several case styles (T62, T72, DO-200, and TO-200 for diodes, and R62, R72, and T9G for SCR's) are designed to operate clamped between heat sinks. There is a spring contact within the device that prevents operation unless the unit is physically compressed. These devices should be tested in place if possible. Otherwise, moderate pressure applied with the fingers is usually sufficient to "make" the internal connection. Apiece of insulating material should be placed between the fingers and SCR surface to prevent false leakage readings.

d. Resistors and rheostats. A resistor is a passive component used to hinder the flow of electric current. Many sizes, shapes, values and types of resistors are available. The most common types are wire wound (resistance wire wound around an insulator) and carbon stick (pressed carbon tubes or rods). A rheostat is simply a variable resistor. Like resistors, rheostats also are made in numerous sizes, shapes, values and types. Again like the resistor, the rheostats are wire wound or carbon composition. The rheostat is normally 3/4 circular in design with a terminal at each end. A movable contact or brush known as the "wiper" rides on the rheostat material surface and can be moved to select the desired resistance value. Use an ohmmeter to accurately measure the resistance of a resistor or rheostat. However to avoid false readings of devices which may be connected in parallel, disconnect one side of the component to be tested before making resistance measurements. Replace components that do not measure within plus or minus five percent of the value given in the manual or as specified on the schematic diagram, unless other tolerances are indicated. Replace broken, cracked or damaged units and support brackets.

e. Zener diodes. A Zener diode is a semiconductor device like the rectifier diode, but the Zener device has its composition and P–N junction characteristics carefully controlled in order to produce a de-



a.



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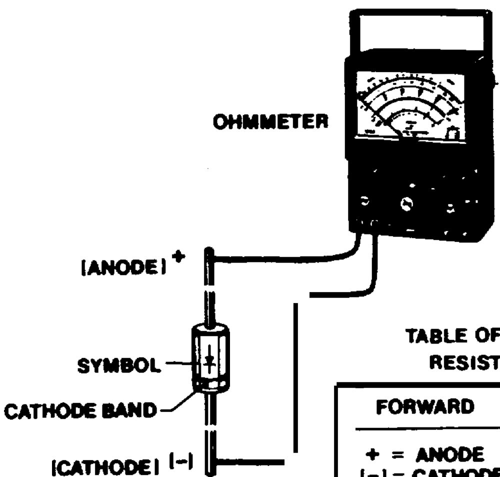


TABLE OF TYPICAL RESISTANCES

FORWARD	REVERSE
+ = ANODE (−) = CATHODE	(−) = ANODE + = CATHODE
x 1 − SCALE	x100 SCALE
SILICON OR SMALL SIGNAL 12 − 100Ω	1,000 − 250,000
GERMANIUM OR LARGE POWER TYPE 5 − 15Ω	1,000 − 100,000

c.

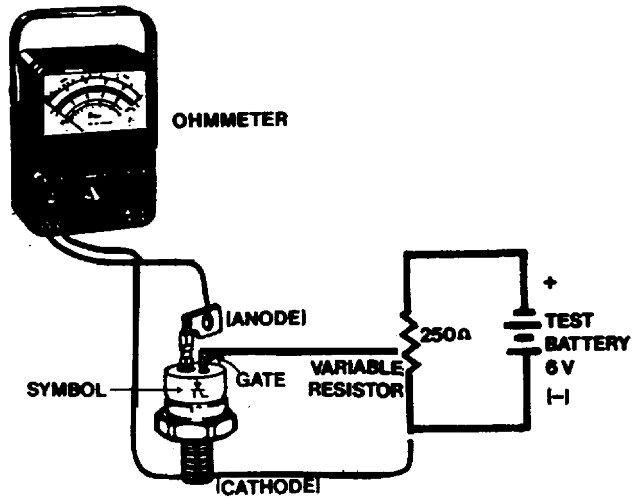


TABLE OF TYPICAL RESISTANCES

ON	BLOCKING FWD. OR REV.
$V_G - T_H$ ≥ 0.2V TO 1.6V	$V_G - T_H$ 0 − 0.2V OR (OPEN)
6 − 80Ω	10,000 − 500,000 Ω

d.

Figure 7-2. Diodes and SCR's: a) Various package styles, b) symbols and polarity, c) Testing a Diode, d) Testing an SCR.

sired breakdown voltage in the reverse direction. The Zener diode will provide rectification in its forward mode; however, the precise voltage developed across its reverse junction is of greater interest. This property is useful as a voltage reference. No significant reverse current flows until the Zener voltage (V) is reached. At this point, a sharp increase in reverse current occurs as illustrated in figure 7-3 characteristics “A” and "B". The device will maintain its voltage over a considerable range of reverse current. It should be noted that any diode, but especially Zener diodes, should be operated with some means of external series resistance in order to limit the maximum current flow to within the rating of the device. The Zener diode can be manufactured to produce reverse breakdown (Zener) voltages from 0.5-100.0 volts or more with power ratings from 025W—100W. The Zener diode is teated like the general purpose rectifier diode; however, its Zener voltage (V) cannot be determined using the ohmmeter tests. An external test voltage must be applied to determine V (fig 7-4).

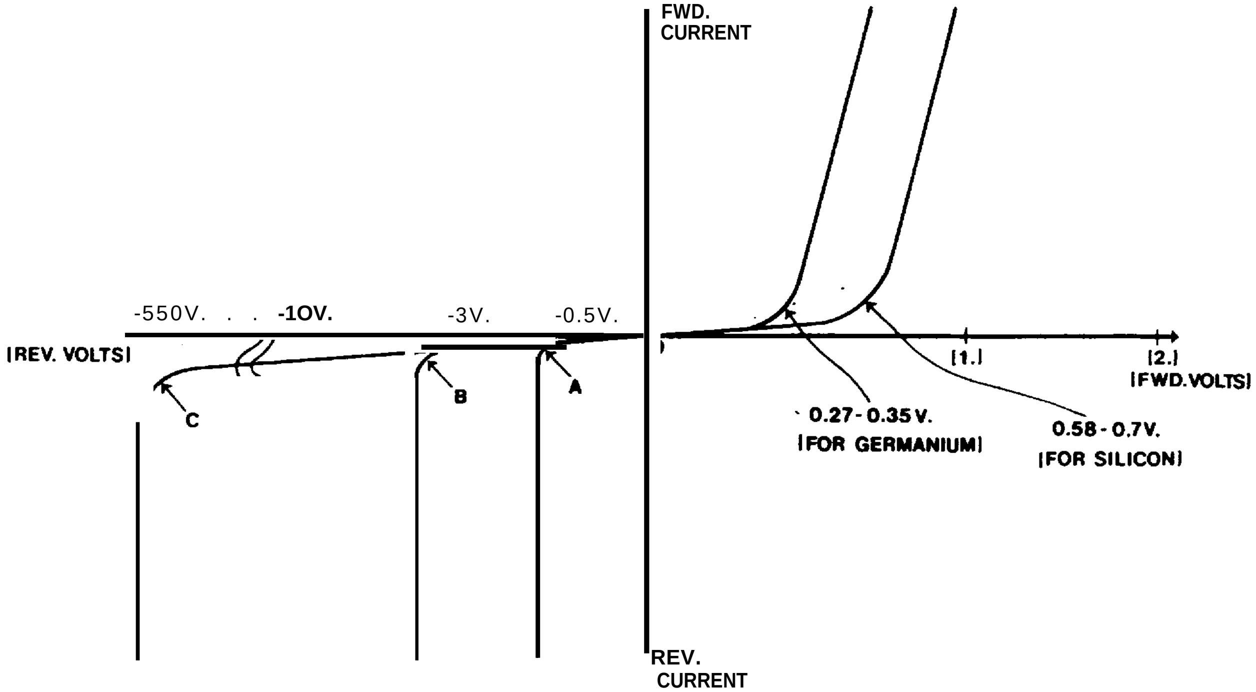


Figure 7-3. Characteristics of Diodes and Zeners: a) Zener action at 0.5V, b) Zener action at 3.0V, c) Reverse breakdown (PRV, PIV, v_{rrm}) for a rectifier Diode.

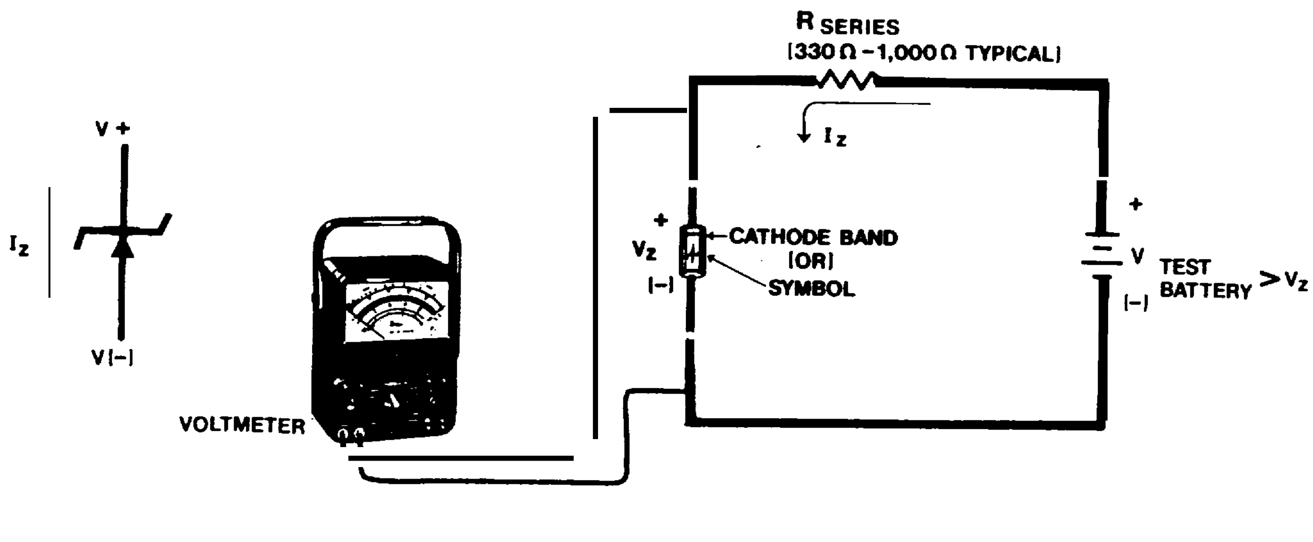


Figure 7-4 Testing Zener Voltage.

f. Transistors. Transistors are three terminal, solid state devices constructed so that the current across the base-emitter junction will control a greater amount of current crossing the collector-emitter junction. Because a smaller current can control a larger one, the transistor provides gain or amplification. Transistors vary in size, power, and voltage ratings. Some idea of the electrical values, type, and application of the transistor in the circuit should be known before testing is attempted.

(1) *Testing.* The bipolar junction transistor (BJT) is tested just like the general purpose rectifier diode. These transistors are actually two diode junctions combined in such a way as to obtain current control. General purpose transistor testing is done as follows (fig 7-5):

(a) Check the polarity of the test leads and zero the ohmmeter.

(b) Determine the type of transistor to be tested, that is whether it is a positive, negative, positive (PNP) or a negative, positive, negative (NPN) junction type.

(c) Set the scale multiplier to “X1” or “L0” and recheck for zero ohms.

(d) Test all combinations as shown in the diagrams and tables given in figure 7-5a or 7-5b.

(e) Test all combinations as shown with the scale multiplier set to "X100” or “H1”. If the values shown in the tables are not obtained, the transistor part number should be checked to confirm its type, or the unit should be replaced if the type is known to be correct.

g. Other solid-state devices. There are numerous other types of solid-state devices used in modern electronic and control systems. Most of these cannot be statically tested with an ohmmeter and expected to give meaningful results. The following is a brief list of devices that yield valid test results only in a circuit:

(1) Field-effect transistors (FETs), metal-oxide semiconductor field-effect transistors (MOSFETS), or insulated-gate field-effect transistors (IGFETs).

(2) Unijunction Transistors (UJTs) or Programmable Unijunction Transistors (PUTs).

(3) Analog Operational Amplifiers and Integrated Circuits.

(4) Any class of Digital Logic Integrated Circuit.

7-3. Electrical disturbances (power quality).

Equipment with sensitive electronic circuits (digital clocks, VCRs, computers, data terminals) may experience memory loss, system malfunction and even component failure due to electrical power source disturbances. Sags, surges and harmonics are some common types of disturbances. Disturbances caused by other customers or even by customer’s own equipment may also affect customer’s equipment. “Power quality” is a relatively new term used to describe the quality of power (absence of voltage dips, surges, harmonics outages, frequency variation) at the user’s location. Traditional measurements for reliability studies don’t deal with the power quality needs of sensitive electronic equip ment. Rather, they deal with the permanent or prolonged outage and how to improve upon it. While this is indeed important to sensitive loads, there is increased concern for short term or momentary disturbances. In addition to voltage limits, sensitive loads such as computers typically require the frequency to be within plus or minus .05 Hz, the rate of change of frequency less than 1 Hz/sec, voltage waveform distortion under five percent and voltage unbalance less than three percent. For specific applications, the power quality requirements should be obtained from the manufacturer of the sensitive equipment. Some of the common types of disturbances, the symptoms, causes and effects are summarized in table 7-1.

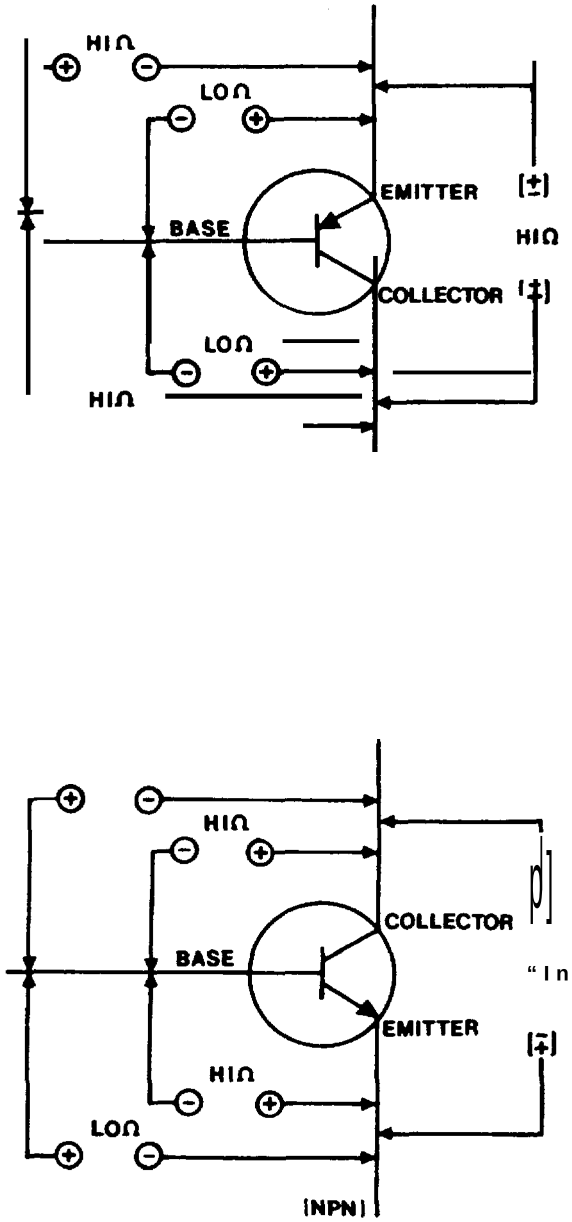
7-4. Disturbance measurement and monitoring.

Conditions may be quite different at any given site, and it is desirable to obtain specific data about the actual situation, if possible, before considering a remedy. If it is an existing site, it is useful to obtain any historical data which might correlate sensitive equipment operation with power disturbances. The type of data includes the sensitive equipment operating log and maintenance records, and electric utility operating log and voltage recordings.

a. The most useful activity for any existing site is to conduct a site power line disturbance study for a one or two month period-including the storm season, if possible. The monitoring should be at the same point that powers the sensitive equipment and must use equipment capable of recording the types of transients that can affect sensitive loads.

b. There are several types of equipment designed to perform this monitoring function. Unlike the traditional strip or circular chart recorders, this equipment is capable of recording variations of voltage in the short time periods of interest for sensitive equipment, yet operate continuously for weeks at a time. Much of the equipment is of the digital readout type which, unfortunately, can lead to improper interpretation of the conditions at the site because it cannot always distinguish between harmless and harmful disturbances.

c. Much more useful monitors produce an analog recording of the disturbances with the ability to expand the waveforms to examine them in detail.



TYPICAL RESISTANCE VALUES FOR MOST BIPOLAR JUNCTION TRANSISTORS

FORWARD JUNCTIONS LOΩ x 1 SCALE	REVERSE JUNCTIONS HIΩ x 100, x 1000 SCALE
PNP-TYPE EMITTER TO BASE COLLECTOR TO BASE 8-20Ω	PNP-TYPE BASE TO EMITTER BASE TO COLLECTOR 1000-50,000Ω COLLECTOR-EMITTER ALWAYS GREATER THAN 10,000Ω
NPN-TYPE BASE TO EMITTER BASE TO COLLECTOR 8-20Ω	NPN-TYPE EMITTER TO BASE COLLECTOR TO BASE 1000-50,000Ω COLLECTOR-EMITTER ALWAYS GREATER

Figure 7-5. Transitor Testing: a) PNP type, b) NPN type.

With this data, it is possible to determine if a disturbance is harmful or not by comparing it with specific tolerance requirements for the sensitive equipment actually used on site. This tolerance information is generally available from sensitive equipment manufacturers upon customer request. With the expanded waveform capability, it is often possible to examine transients and observe a characteristic "signature" which will identify the source of the disturbance.

7-5. Voltage surge suppression.

Voltage surges on a power system are a common power problem experienced by sensitive electronic equipment and mostly seen by the computer user. These transients can be the cause of lost data, false triggering and equipment failure. These transients are generated both internally by the user and externally on the utility primary due to lightning and equipment switching. Many different types of volt-

Table 7-1. Power quality problems summary.

PROBLEM TYPE	SYMPTOMS	CAUSES	EFFECTS
TRANSIENTS (General) • duration: $\leq$ 0.5 cycles ($\leq$8 ms) • coupling mechanism: conductive, electromagnetic. • Transient problems are mainly due to the increased use of sensitive electronic equipment without regard for the realities of normal power system operation and the operation of the customer's facility. • It is very fficu trace source transient. ransients sual have less energy momentary sturbances • If transient suppressors are to be selected for protection, it is important to select compatible, effective, high quality product. • There is a general consensus that most transients get into computer logic and memory circuits by poor grounding or EMI, not by conduction.	• high amplitude, short duration voltage disturbance • can occur in common and normal mode	• switching inductive loads on or off (motors, relays, transformers, x-ray equipment, lighting ballasts) • consumer loads (personal computers, VCRs, refrigerators, washers & dryers, microwave ovens, light dimmers) • operation of UPS/SPS systems may cause notching • arcing ground • lightning • capacitor switching • fault clearing	• data alterations • microprocessor-based equipment errors • hardware damage of electronic equipment • current limiting fuse operation
Impulses rans Categ	• Notches - out-of-phase impulses which decrease the instantaneous voltage. • Spikes - in-phase impulses which increase instantaneous voltage	• Normal mode impulses are typically the result of the switching of heavy loads, or of power factor correction capacitors. • Common mode impulses are often used by lightning.	Same as above.
Oscillations (Transients Category	Damped high frequency oscillations from a few hundred Hz to 500 kHz) that decay to zero within a few milliseconds		Same as above.

Table 7-1. Power quality problems summary—continued.

PROBLEM TYPE	SYMPTOMS	CAUSES	EFFECTS
Voltage Deviations (Long Term) • duration: 2 secs or longer • coupling mechanism conductive • under voltage - a list of overloaded distribution transformer can indicate areas prone to undervoltage conditions. • Undervoltages can be reduced by practicing regular maintenance of appliances, cable and connections, checking for proper fuse ratings, transferring loads to separate circuits, increasing feeder rating or voltage, selecting a higher transformer tap setting, replacing an overloaded transformer or providing an additional feeder.	Any long term change above (overvoltages) or below (undervoltages) the prescribed input voltage range for a given piece of equipment.	Undervoltages may be caused by: • overloaded customer wiring • loose or corroded connections • unbalanced phase loading conditions • faulty connections or wiring • overloaded distribution system • incorrect tap setting.	Undervoltages cause: • errors in sensitive equipment operation • low efficiency and reduced life of electrical equipment such as motors, heaters • lengthens process time of infrared and resistance heating processes • hardware damage • dimming of incandescent lights, and problems in turning on fluorescent lights.
Brownouts	A type of voltage fluctuation. Usually a 3-5% voltage reduction.	• poor wiring or connections • high power demand within building or local area • intentional utility reduction to reduce load under emergency system conditions, very rarely done • planned utility testing	• Overheating and reduced line of electrical equipment and lighting • Blistering of infrared processes
Overvoltages	• High voltages during low load levels.	Overvoltages may be caused by: • improper application of power factor correction capacitors • incorrect tap setting.	Overvoltages cause: • overheating and reduced life (insulation) of electrical equipment and lighting • blistering of infrared processor

Table 7-1. Power quality problems summary—continued.

PROBLEM T	SYMPTC	CAU	EFFE
MOMENTARY PROBLEMS (General) • duration: 0.5-120 cycles (8 ms-2s) • coupling mechanism: conductive Sags/Voltage Flicker: • When starting large loads, such as motors, high inrush currents are produc which drop the voltage for short period: This is a relatively common problem an can be prevented by using reduced volt motor starters, by reducing the number large loads operating simultaneously, b restricting the number of motor starts a given time, by transferring the large lo its own circuit, by upgrading feeder voltage, by using cable of proper rating and by choosing equipment that is compatible with applicable Standards an the utility voltage flicker curve.	• Sags - Low voltage on or more phases. • Voltage Flicker - receptive sags or su in the voltage.	• starting large loads (motors, air conditioners, electric furnaces, etc.) • overload wiring and incorrect fuse ra • fuse and breaker clearing • lightning (indirect cause due to effect lightning arresters) • ground faults • utility switching/equipment failure • large cyclic loads such as spot welde induction or arc furnaces, and motors when cycled.	• common cause of power related computer system fail • hardware damage unlikely • flickering of lights • motor stalling • reduced life of motors and dr equipment • digital clock flashi • TV picture size ch
Swells • duration 0.5-120 cy	High RMS voltag disturbance on on more phases.	• open neutral connection • insulation breakdown • sudden load reduction • improper wiring, which restricts the amount of current available for loads • fault on one line causing voltage ris other phases • open conductor fault	• light flicker • degradation of electrical con • TV picture size change • not very troublesome usuall

Table 7-1. Power quality problems summary—continued.

PROBLEM TYPE	SYMPTOMS	CAUSES	EFFECTS
Voltage Deviations (Long Term) • duration: 2 secs or longer • coupling mechanism conductive • under voltage - a list of overloaded distribution transformer can indicate areas prone to undervoltage conditions. • Undervoltages can be reduced by practicing regular maintenance of appliances, cable and connections, checking for proper fuse ratings, transferring loads to separate circuits, increasing feeder rating or voltage, selecting a higher transformer tap setting, replacing an overloaded transformer or providing an additional feeder.	Any long term change above (overvoltages) or below (undervoltages) the prescribed input voltage range for a given piece of equipment.	Undervoltages may be caused by: • overloaded customer wiring • loose or corroded connections • unbalanced phase loading conditions • faulty connections or wiring • overloaded distribution system • incorrect tap setting.	Undervoltages cause: • errors in sensitive equipment operation • low efficiency and reduced life of electrical equipment such as motors, heaters • lengthens process time of infrared and resistance heating processes • hardware damage • dimming of incandescent lights, and problems in turning on fluorescent lights.
Brownouts	A type of voltage fluctuation. Usually a 3-5% voltage reduction.	• poor wiring or connections • high power demand within building or local area • intentional utility reduction to reduce load under emergency system conditions, very rarely done • planned utility testing	• Overheating and reduced line of electrical equipment and lighting • Blistering of infrared processes
Overvoltages	• High voltages during low load levels.	Overvoltages may be caused by: • improper application of power factor correction capacitors • incorrect tap setting.	Overvoltages cause: • overheating and reduced life (insulation) of electrical equipment and lighting • blistering of infrared processor

Table 7-1. Power quality problems summary—continued.

Power interruptions • duration of momentary interruptions: 2 mins. or less • duration of sustained interruptions: 2 mins. or longer • coupling mechanism: conductive • Review Overcurrent Protection in Distribution System. • Solutions include employing UPS systems, allowing for redundancy, or installing generation facilities in the customer's facility.	Total loss of input voltage. Often referred to as "blackout" or "failure" for events of a few cycles or more, or "dropout" or "glitch" for failures of shorter duration.	• operation of protective devices in response to faults that occur due to acts of nature or accidents • malfunction of customer equipment • fault at main fuse box tripping supply	• loss of computer/controller memory • equipment shutdown/failure • hardware damage • product loss

Voltage Phase Unbalance
 	
• duration: 2 seconds or longer
• coupling mechanism:
  • conductive
  • electromagnetic
• Only affects 3 phase customers
• Usually due to customer hook-ups of large single phase loads
• Survey all feeders regularly to prevent this problem
• Can be improved by load reconnections.
	Unequal phase voltages in magnitude and/or angle	• unbalanced phase loading conditions
		
		• defective transformers
		
		• ground faults
			• premature failure of motors and transformers due to overheating

Frequency Deviation • duration: continuous • coupling mechanism: conductive • The frequency of public power in North America is virtually standard at 60 Hz. Most of the rest of the world has a 50 Hz supply. • The frequency is usually very stable.	Variation of frequency from 60 cycles per second can be higher or lower.	• under upset conditions, usually very rare.	• malfunctioning of timing circuits and disk and tape drives • malfunctioning of ferroresonant transformers

Table 7-1. Power quality problems summary—continued.

Harmonic Distortion • duration: continuous • coupling mechanism: conductive, electromagnetic • Ideally, harmonics should be suppressed at the source	Voltage deviation from a true sine wave, due to unwanted frequencies that are multiples of the fundamental (60 Hz)	• Operation of any static power converter which converts AC to DC or DC to AC, or any solid state switch, or equipment containing these devices (electric variable speed drives, many computer power supplies, dimmer switches, variable speed drills, UPS) • welding equipment • induction furnaces • arc furnaces • microwave ovens • battery chargers (e.g. UPS or vehicle) • elevators • saturated utility transformers	• serious damage to capacitors and transformers. • decreased motor performance (reduced efficiency, overheating, torque pulsations) • premature equipment failure • maloperation of control equipment; false triggering of SCRs • interference with computers • amplification of harmonic levels due to resonance • incorrect readings on mechanical timing relays and watt-hour meters • blown fuses • humming on telephones • television interference
Electrical Noise • duration: continuous • coupling mechanism: conductive, electromagnetic, common impedance	Low level signal superimposed on the power sine wave. Similar to a continuous or cyclic occurrence of transient oscillations, in common and normal mode.	• improper grounding often causes common mode noises • loose or corroded connections • insulator leakage • welding • radio and TV transmitters • gas discharge lamps • poor motor brush contact • normal operation of computers and electronic equipment • lightning • switching of customer loads	• data alterations • microprocessor-based equipment errors • increased audible noise • communication interference

Table 7-1. Power quality problems mary—c

PROBLEM TYPE	SYMPTOMS	CAUSES	EFFECTS
MOMENTARY PROBLEMS (General) • duration: 0.5-120 cycles (8 ms-2s) • coupling mechanism: conductive Sags/Voltage Flicker: • When starting large loads, such as motors, high inrush currents are produced which drop the voltage for short periods. This is a relatively common problem and can be prevented by using reduced voltage motor starters, by reducing the number of large loads operating simultaneously, by restricting the number of motor starts at any given time, by transferring the large load to its own circuit, by upgrading feeder voltage, by using cable of proper rating, and by choosing equipment that is compatible with applicable Standards and the utility voltage flicker curve.	• Sags - Low voltage on one or more phases. • Voltage Flicker - receptive sags or surges in the voltage.	• starting large loads (motors, air conditioners, electric furnaces, etc.) • overload wiring and incorrect fuse rating. • fuse and breaker clearing • lightning (indirect cause due to effects of lightning arresters) • ground faults • utility switching/equipment failure • large cyclic loads such as spot welders, induction or arc furnaces, and motors when cycled.	• common cause of power related computer system failures • hardware damage unlikely • flickering of lights • motor stalling • reduced life of motors and driven equipment • digital clock flashing • TV picture size change
Swells • duration 0.5-120 cycles	High RMS voltage disturbance on one or more phases.	• open neutral connection • insulation breakdown • sudden load reduction • improper wiring, which restricts the amount of current available for loads • fault on one line causing voltage rise on other phases • open conductor fault	• light flicker • degradation of electrical contacts • TV picture size change • not very troublesome usually

age suppressors, filters, etc. are used to protect the sensitive electronic equipment. These types of equipment are called power conditioners.

a. Transient suppressors. Transient suppressors are very low cost devices available for microcomputers in the form of outlet strips similar to extension cords with multiple receptacles. They usually contain metal oxide varistors (MOVS) and sometimes silicon avalanche diodes (SADS). These are typically disc shaped devices connected between the power lines and, sometimes, from line to ground. They absorb energy from transients which exceed their threshold (typically 100 percent above normal peak voltage). Because of their small size and low cost compared with the equipment they serve and the cost of determining if such transients exist at a given installation, many people provide this protection as insurance. This type of transient suppressors can be provided for a nominal cost and most of the more expensive power conditioners such as line voltage regulators, static switches and UPS systems have these devices built in. They can even be added to a distribution panelboard, if not included elsewhere. Another form of transient suppressor, a surge arrester, is intended to lower the transient energy level to that which can be handled by downstream power conditioners, such as MOVS or filters. They typically use gas discharge tubes which are slower acting than MOVS, but can absorb more energy. To be effective, however, they too must be coordinated with upstream surge arresters having greater energy absorbing capability. Usually, this is done at each point of voltage transformation back to the incoming line and is best coordinated with the electric utility. Packaged transient suppressor systems combining the devices described above are available which, when properly installed, will limit expected surges as defined by the IEEE Standard C62.41.

b. Filters. Line filters are used to reduce electromagnetic interference (EMI) and/or radio frequency interference (RFI) to acceptable levels. Generally small and low in cost, they, too, are usually built into sensitive equipment and the more expensive power conditioner equipment. The simplest form of filter, a low pass filter, is designed to pass 60 Hz voltage but to block the very high frequencies or steep wavefront transients. They are not effective for frequencies near 60 Hz, such as low order harmonics, but become effective in the Khz range. Filters can be connected line to line or line to neutral for rejection of normal mode noise. They can also be connected line to ground for common mode noise rejection. Some of the better transient suppressor outlet strips also contain these falters.

c. Isolation transformers. Isolation transformers are more expensive power conditioners. They provide two functions. One is the ability to change to a new voltage level and/or to compensate for high or low site voltage. For example, by using 480V input up to the point of use and then transforming to 120V or 208Y/120V, the switchgear and wiring can be reduced in size and the effect of line drop reduced. If the voltage at the point of use is too low due to line drop, it can be manually boosted in steps by connecting to different taps on the transformer windings. The second function of the isolation transformer is to provide for the ground reference right at the point of use. This eliminates the problem of common mode noise induced through “ground loops” or multiple current paths in the ground circuit upstream of the established reference ground point.

d. Voltage regulators. Most of the voltage problems except outages can be handled by the addition of voltage regulators equipped with transient suppressors. Several solid-state techniques have been developed in recent years to replace the older, slow acting electro-mechanical type. One type of fast response regulator is the phase modulating type. It usually utilizes thyristor (SCR) control of buck and boost transformers in combination with filters to provide stable sinusoidal output even with nonlinear loads typical of computer systems. This is done in a smooth continuous manner, but at great speed, eliminating the steps inherent in the tap changer. Heavy loads can be delivered for start-up inrush typical of computer central processors or disc drive motors while maintaining full voltage.

e. Motor generators. Motor generators consist of an electric motor driving an AC generator so that the load is electrically isolated from the power line. Motor generators are used widely as a source of 400 Hz power for large computer central processors requiring this frequency. Because the frequency tolerance of the computers is wide, a simple induction motor can be used to drive a brushless synchronous generator (alternator). The speed changes with load and input voltage variations hold output frequency well within tolerance and constant voltage is maintained by automatic voltage regulators controlling the generator’s field excitation.

f. Uninterruptible power supplies (UPS). For continuous operation of computer or other sensitive systems when line voltage is interrupted, the only solution is a UPS. A properly designed UPS can provide computer quality power under essentially all normal and abnormal utility power conditions during outages for extended period of time depending on battery capacity. This bridges most power outages and permits orderly shutdown for longer outages. UPS systems are typically solid-state without any rotating machinery. However, some designs incorporate motor generator sets in addition to solid-state circuitry and batteries to supply continuous power. These systems are commonly known as rotary UPS. A rotary UPS electrical output is usually more sinusoidal than a solid-state UPS and is less susceptible to distortion.